Jet-fan Inverter Control System

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Contents

1. Jet-fan Inverter Ventilation Control System	**P1**
2. Longitudinal Ventilation Tunnel and Jet-fan Inverter Control	**P2**
3. Normal State Ventilation Control	**P3**
4. Fire Emergency State Ventilation Control	**P4**
5. New Ventilation Control System – FCVC， FCVC-N	**P5**
6. Jet-fan Inverter Control Panel – JINV	**P7**

1. Jet-fan Inverter Ventilation Control System

Summary

A new ventilation control system driving jet-fan by an inverter hardware and control software is offered to the market for energy saving and improved safety in road tunnel ventilation.

Most of the road tunnels employ **longitudinal ventilation method** using jet-fans. The road tunnel ventilation is classified into two states of control: one for **normal state ventilation control** with the goal of keeping the tunnel air pollution below the target levels, and the other for **fire emergency state ventilation control** with the goal of securing passengers' evacuation and firefighters' safety during rescuing and fire extinguishing operations. Fixed speed jet-fan control has been used by selecting suitable number of units for either state of ventilation control.

Jet-fan inverter control realizes a new system which replaces the conventional fixed speed jet-fan control. The jet-fan inverter control system mainly consists of **"FCVC/ FCVC-N"**, a new ventilation control method, and **"JINV"**, a jet-fan inverter control panel. Those two have made possible the jet-fan inverter control which was considered difficult to achieve.

In developed society, people demand for higher level of improvement in environment and safety. In road tunnels, lower air pollution level than previously achieved is enforced more often than before during the normal state control due to the improved vehicle exhaust gas emission. On the other hand, improved safety is demanded during the emergency state control caused by vehicle fire. The jet-fan inverter control has begun to be accepted in the market as the ultimate solution to meet those requirements.

Sohatsu Systems Laboratory Inc. completed **development of jet-fan motor inverter control method in two-way traffic tunnel** with the fund of "Practical Research and Development Initiative" as a part of "Challenge Support Initiative for Small and Medium Size, and Venture Companies" sponsored by Ministry of Economy and Trade Industry in 2007. Sohatsu has also been promoting the five (5) year project for **"Development and Commercialization of New Tunnel Ventilation Control System by Driving Jet-Fan with Inverter"** sponsored by METI and Ministry of Land, Infrastructure and Tourism's initiative for New Business Incubation Plan through Synergetic Collaboration since 2008. The achievements of those projects are published in the international symposiums such as BHR 13th ISAVVT and 14th ISAVT. Sohatsu Systems Laboratory Inc. won the best paper award for **"The Use of Inverter-Driven Jet-Fan to Reduce Ventilation Cost"** at BHR 13th ISAVVT in 2009.

Project fund apprived by Ministry of Economy, trade and Industry in 2007

Project fund approved by Ministry of Economy, Trade and Industry and Ministry of Land, Infrastructure, Transport and Tourism in 2008 to 2010

Best Paper prize awarded at 13th BHR ISAVVT in 2009

2. Longitudinal Ventilation Tunnel and Jet-fan Inverter Control

Longitudinal Ventilation Method with Jet-Fan Inverter

Longitudinal ventilation method creates air flow in the tunnel tube with jet-fans and ventilates polluted air. The method is widely employed in Japan and world wide. Aside from the single tube application, **longitudinal ventilation method** is applied in various ways which include the vertical shaft blower/exhauster longitudinal ventilation, and the concentrated exhauster longitudinal ventilation (Fig. 1).

The jet-fan control system for longitudinal ventilation consists of “instrumentation panel” where sensor signals from VI, CO, AV, Traffic Counter, Fire Detector, Emergency Situation Detector and etc. are gathered, “ventilation control panel” where control SW determines the speed of the jet-fans, and “jet-fan inverter panel” where the electrical voltage is generated to actually drive the jet-fans. Fig. 2 illustrates a conceptual diagram of the jet-fan inverter control system.

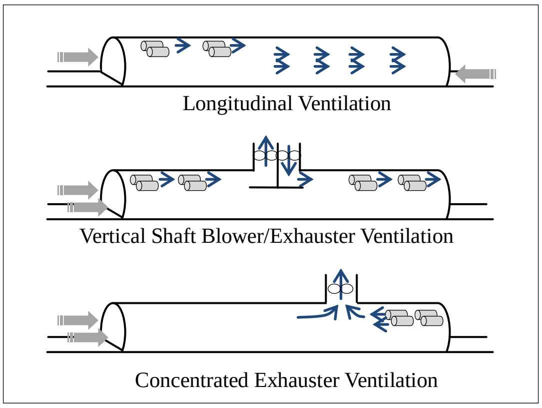

Fig. 1 Various Longitudinal Ventilation Methods

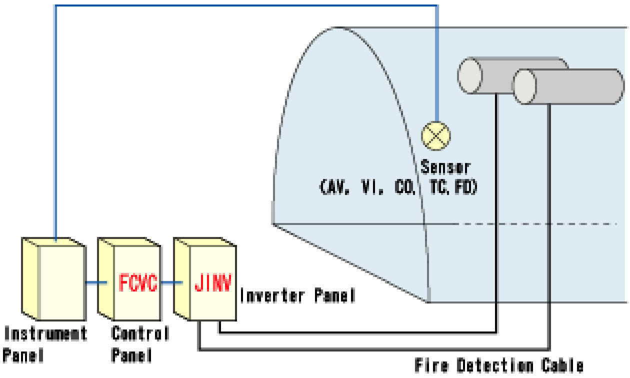

Fig. 2 Jet-fan Inverter Control System

Merits of Jet-Fan Inverter Control

The jet-fans are driven at variable speed by **inverter** which generates **variable voltage** and **variable frequency power source**. An immediate advantage of the jet-fan inverter is that as it increases the jet-fan speed gradually, it does not cause excessive in-rush current during start-up operation unlike constant speed control. Table 1 compares **variable speed control** and **constant speed control**.

Table 1 Comparison between Variable Speed and Constant Speed Control

Comparison Items		Constant Speed Control		Variable Speed Control	
Start-Up Characteristics	Startup Current	3 to 5 times of rated current required	△	Rated current is enough to start	○
	Startup of Multiple Units	Restriction in multiple unit start up simultaneously due to startup current	△	No restriction in multiple unit startup simultaneously	○
Operation Characteristics	Response (Emergency State)	Lack of fast response due to many startup restrictions	△	Fast response with no startup restriction	○
	Energy Saving (Normal State)	Large power consumption due to rated power operation	△	Less power consumption due to multiple unit operation below rated power	○
Equipment	Power transformer	Startup current capacity required	△	Rated current capacity required	○
	Countermeasure against higher harmonics	Not required	○	Required if small power source capacity	△
	Ventilation Power Panel	No additional panel required	○	Inverter Panel required	△
	Noise Filter	No additional device required	○	Device required to reduce interference to communication and radio equipments	△
	Power Cable	Voltage drop by rated and startup current	△	Voltage drop by rated current	○

INFO Sohatsu is pleased to provide consulting service for converting existing constant speed control to variable speed control.
http://www.sohatsu.com/

3. Normal State Ventilation Control

Principle of Energy Saving Operation

In longitudinal ventilation, the jet velocity, thrust and power consumption of jet-fan is almost in proportion to jet-fan speed, square of jet-fan speed and cube of jet-fan speed respectively (Fig. 3). The jet-fan speed is proportional to the electrical power frequency driving the jet-fan motor. Therefore, the output air velocity, thrust and power consumption of jet-fan is controlled by the use of **inverter** which works as **variable voltage** and **variable frequency power source**.

In **constant speed control**, the thrust required for tunnel ventilation is achieved by adjusting the number of running jet-fans. For example, more units of jet-fans are in operation to increase the thrust. In **variable speed control**, the thrust required for ventilation is achieved by adjusting the speed of all jet-fans which run at the same frequency. For example, the frequency is increased to all jet-fans to increase the thrust (Fig. 4). **Variable speed control** can consume less electrical power than **constant speed control** in achieving the same thrust. This is **the principle of energy saving operation with the use of inverter control**.

Fig. 4 and Table 2 illustrate the energy saving amount when running five (5) jet-fans.

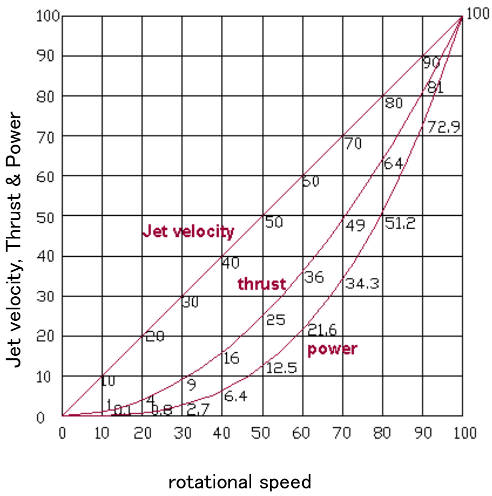

Fig. 3 Characteristics of Jet-fan Inverter Control

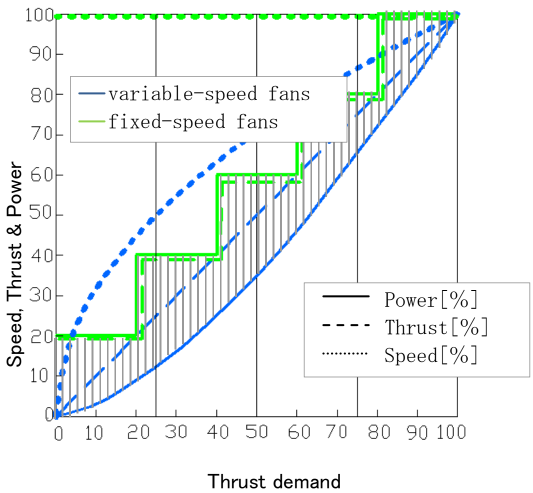

Fig. 4 Principle of Energy Saving of Jet-fan Inverter Control

Power Consumption in Variable Speed and Constant Speed Control

Table 2 Power Consumption in Variable Speed and Constant Speed Control

Thrust	Constant Speed			Variable Speed			Energy Saving
	Number of Units in Operation	Output Air Velocity	Power Consumption	Number of Units in Operation	Output Air Velocity	Power Consumption	
20%	1 Unit	100%	20%	5 Units	45%	9%	55%
40%	2 Units	100%	40%	5 Units	63%	25%	37%
60%	3 Units	100%	60%	5 Units	77%	46%	23%
80%	4 Units	100%	80%	5 Units	89%	72%	11%
100%	5 Units	100%	100%	5 Units	100%	100%	0%

ATTN In the case jet-fans are combined with blowers and exhausters for ventilation, the jet-fan inverter control contributes a lot to energy saving in the blowers and exhausters.

INFO Sohatsu is pleased to provide consulting service for evaluation of energy saving in planned tunnel.
http://www.sohatsu.com/

[Paper] "The Use of Inverter-Driven Jet-fans to Reduce Tunnel Ventilation Costs", BHR 13th ISAVVT, p69-p80, 2009, won the best paper award. The abstract is available in the web site: http://www.sohatsu.com/Jsite/infomrtaion/i-2.htm.

4. Fire Emergency State Ventilation Control

Principle of Improved Safety Operation

When **vehicle fire incident** happens in the **longitudinal tunnel**, the heat and smoke caused by the fire propagate in the direction of tunnel air velocity. If the tunnel is **two-way traffic** or it is **one-way with a traffic jam**, passenger safety becomes at risk as there are slow moving or stopped vehicles in the direction that air is flowing.

To secure passenger evacuation and safety, **air velocity "zero" control** was employed in the first phase of the Kanetsu Tunnel (11km long, two-way traffic, and 48 units of jet-fans). **Air velocity "zero" control** aims at keeping air velocity at zero in the tunnel to hold heat and smoke on the tunnel ceiling (Fig. 5).

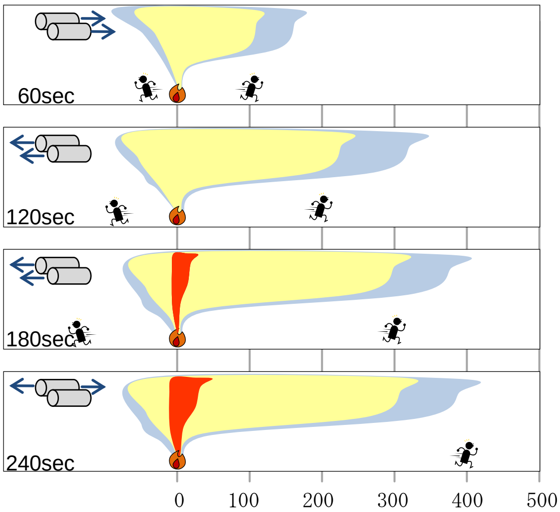

Fig. 5 Illustration of Passenger Evacuation and Heat/Smoke Diffusion under Air Velocity Zero Control

Air Velocity Zero Control and Jet-Fan Shutdown Control

In the case there is not enough number of jet-fans installed, it is considered difficult to achieve **the air velocity "zero" control** with the constant speed control due to the fact that jet-fans can't withstand frequent ON/OFF operations. **Jet-fans shut down control** is employed at fire incident in many of the relatively long (1,500m to 4,000m) and two-way traffic tunnels. As showin in Fig. 6, safety risk is yet to be resolved if the air velocity is determined by natual wind and traffic force.

On the ther hand, jet-fan inverter control can achieve the most desirable thurst promptly by controling the speed without any start-up restriction on normal and reverse operations. With this feature jet-fan inverter control can realize easily **the air velocity "zero" control** with a small number of jet-fan units (Fig. 7).

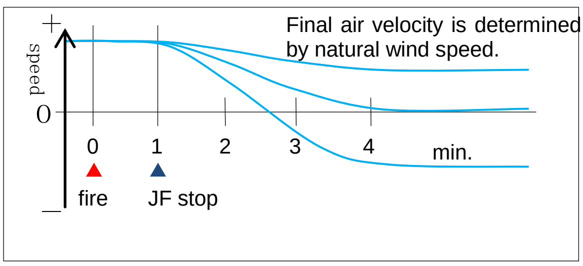

Fig. 6 Jet-fan Shutdown Control

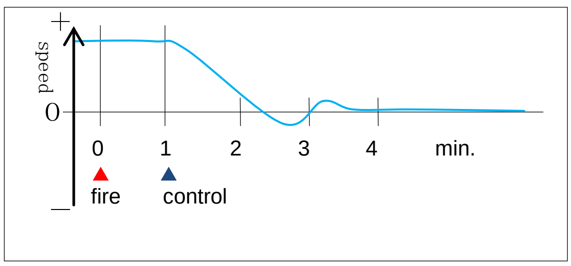

Fig. 7 Air Velocity Zero Control

INFO Sohatsu is pleased to provide consulting service for evaluation of the improved safety operation in planned tunnel.
http://www.sohatsu.com/

【Paper】
- "Emergency Operation of Ventilation for The Kan-Etsu Road Tunnel", Lille 5th ISAVVT in 1985, p77-p91 .
- "Practical Test of Emergency Ventilation Combined with Busfiring at The Kan-Etsu Tunnel", Durham 6th ISAVVT in 1988, p353-p366.
- "Automatic Control of Two-way Tunnels with Simple Longitudinal Ventilation", Graz 5th TSV in 2010, p74-p84.
- Please visit http://www.sohatsu.com/Jsite/information/i-2.htm for the abstracts.

5 New Ventilation Control Panel: FCVC, FCVC-N

Abstract

Feed-forward Cascade Feedback Ventilation Control System **("FCVC")** is a new ventilation control system which has been developed for **jet-fan inverter control**. By adding air velocity feedback loop, **FCVC integrates** seamlessly **normal state ventilation control** and **fire emergency state ventilation control**. **FCVC** and **FCVC-N** can maximize the benefit of the jet-fan inverter control in a way that achieves the energy saving in normal state operation and the improved safety in fire emergency state operation.

Features

① The air velocity feedback loop built in **FCVC** can stabilize the longitudinal air velocity taking advantage of the merit of the variable speed control by the use of inverter.

② In **normal state ventilation control**, the air velocity feedback loop achieves the energy saving operation by combining widely used traffic forecast and VI/CO pollution density feedback loop.

③ **FCVC-N** achieves the ultimate energy saving by adding natural wind measurement to **FCVC**.

④ In **fire emergency state ventilation control**, the air velocity feedback loop running all the time in the normal state operation switches effectively to the air velocity "zero" control and realizes a highly reliable ventilation control.

⑤ **FCVC** realizes a single and unified control structure for both normal state control and fire emergency state control, which were implemented in two separate control structures in the past. Having few control parameters, **FCVC** is quite simple and robust, and can be applied widely to the ventilation control in the longitudinal tunnels.

Case Studies

Fig.8 and 9 illustrate the result of numerical simulation of **FCVC** in a hypothetical tunnel for **normal state ventilation control** and **fire emergency state ventilation control**, respectively. The tunnel studied in simulation is 1,500m long, and operates six (6) jet-fans in the normal state and three (3) jet-fans in the fire emergency state.

Fig.8 shows the jet-fan speed response which tracks well to the daily traffic pattern, and keeps VI faithfully in the range of the target density 60%.

Fig.9 shows the result of the air velocity "zero" control by **FCVC**. It illustrates the fire emergency control initiated one minute after the fire incident, and the air velocity "zero" achieved about 1.5 minutes later (2.5 minutes after the fire incident).

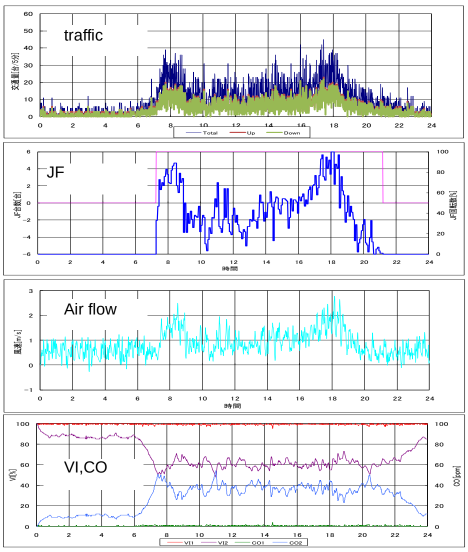

Fig. 8 Result of Sample Normal State Simulation

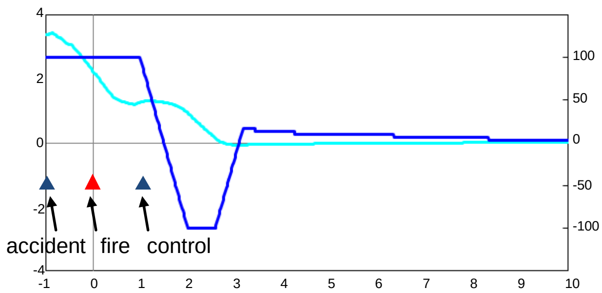

Fig. 9 Result of Sample Fire Emergency State Simulation

5 New Ventilation Control Panel: FCVC, FCVC-N

FCVC System Configuration

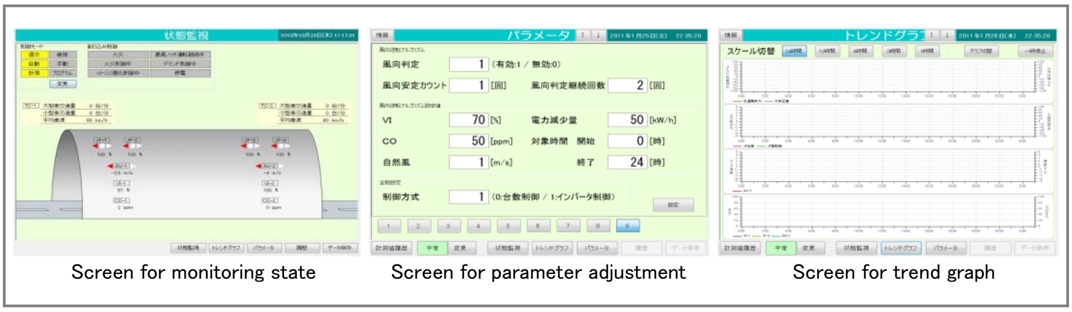

Fig 10 Screen for parameter adjustment

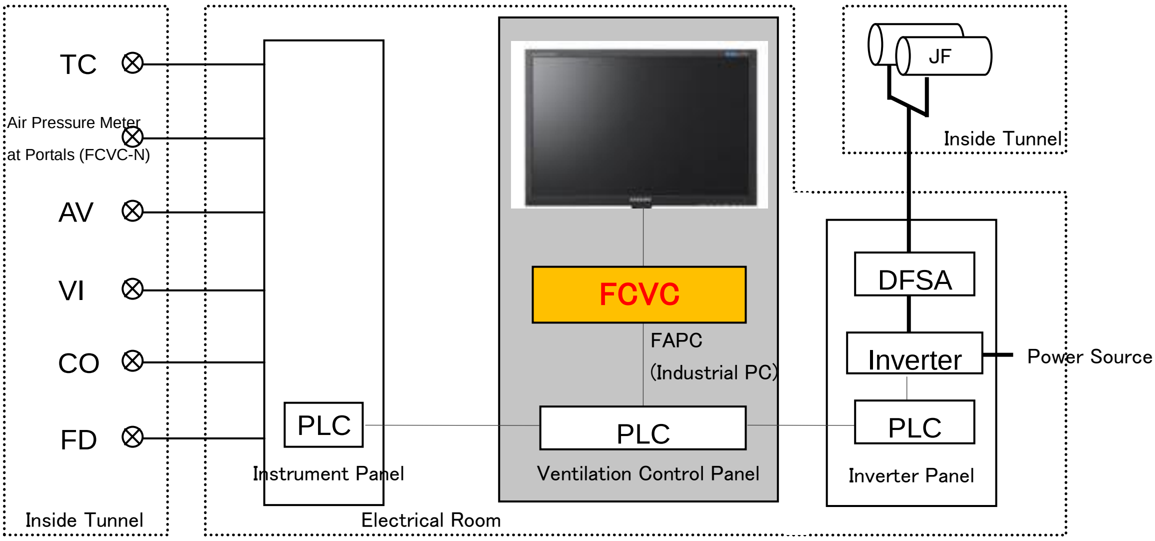

Fig 11 System Configuration

FCVC System Specification

Table 3 FCVC System Specification

	Item	Specification
FAPC	CPU	Intel Pentium Dual-Core Processor (1.80 GHz) or faster
	OS	Windows 2003 Server (Japanese Version) or beyond
	Memory	2GB or larger
	HDD	160GB SATA HDD or larger
	USB	2 ports、Front：USB2.0 Type-A (4pin female)
	Network	10/100/1000 Ethernet Network Controller
	Keyboard, Mouse	Japanese Keyboard、Laser Mouse（*for Maintenance*）
	Monitor	15 inch Resolution 1280x1024（*for Maintenance*）
	Touch Panel	17 inch Resolution 1280x1024（for Operator）

ATTN **FCVC** and **FCVC-N** were developed in three years of collaborative research between Public Works Research Institute and Sohatsu from 2008 to 2010, and are validated effective in the actual tunnel tests.

INFO Sohatsu is pleased to provide consulting service for the use of **FCVC** in planned tunnel.
http://www.sohatsu.com/

【Paper】 - "A New Ventilation Control for Inverter Driven Jet-fans", BHR14thISAVVT in 2011, p431-p445.
Please visit http://www.sohatsu.com/Jsite/information/i-2.htm for the abstract.
- "Research on prediction of natural wind and traffic induced ventilation in road tunnels", 14th BHR ISAVT, 2011, p283-p290.
- "A Study on tunnel ventilation control method using natural wind and traffic induced ventilation force", Ninth Japan Road Congress, 2011. Please visit http://www.pwri.go.jp/jpn/seika/ronbun.html for the abstract.

6. Jet-fan Inverter Control Panel – JINV

Abstract

Jet-Fan Inverter Control Panel ("JINV") is a hardware device with an inverter driving a group of jet-fans at **variable speed in controlling** tunnel air velocity. Combined with the ventilation control panel **FCVC** or **FCVC-N**, **JINV** achieves **energy saving in the normal state control** and **improved safety with air velocity "zero" control in the fire emergency state control**. **JINV** is in operation at an actual tunnel since December 2010 after a few years of research and development.

Features

① **JINV** suppresses the surge voltage in the long distance power cable by employing the newly designed and developed **Distance Free Surge Absorber ("DFSA")** and can be installed **at maximum 3km** away from the jet-fans.

② **JINV** is built in compact **inverter control panel** and replaces the conventional ventilation power panel.

③ **JINV** employs **three (3) level general purpose inverter** and controls noises.

④ The countermeasures against surge and noise are verified and validated for actual use by a lot of experiments and actual operations.

⑤ **Load Free Harmonic Absorber ("LFHA")** is prepared for a counter measure against higher harmonics at power source end.

Example Operation

Je-fans are installed in the tunnel and connected to JINV installed in the electrical room with a long distance power cable as shown in Fig.12. The output voltage of three-level is shown in Fig.13. Three-level inverter reduces the surge voltage significantly compared with two-level inverter. Combining three-level inverter and DFSA can suppress the surge voltage to jet-fan motor and the noise level to other tunnel equipments within tolerant level.

Fig.14 illustrates the input voltage to inverter, output voltage and output power of inverter when jet-fan is driven in various speeds.

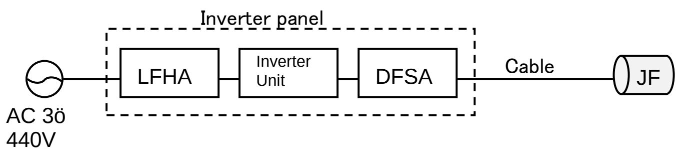

Fig. 12 Connection between Jet-fan and JINV

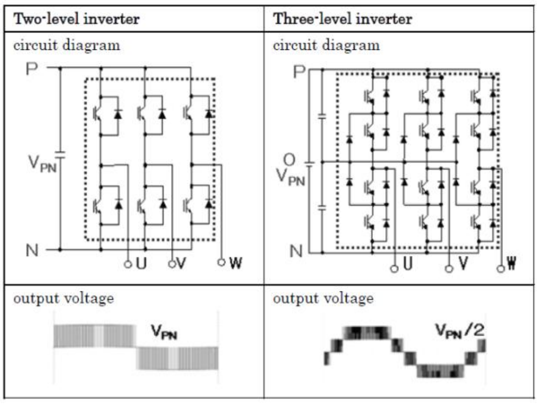

Fig 13 Comparison of 2-level and 3-level inverter

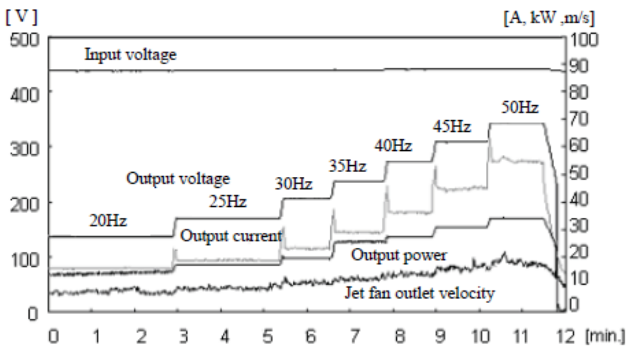

Fig 14 Input voltage to inverter and output voltage / power of inverter when driving jet-fan in various speeds

6. Jet-fan Inverter Control Panel – JINV

Panel Configuration

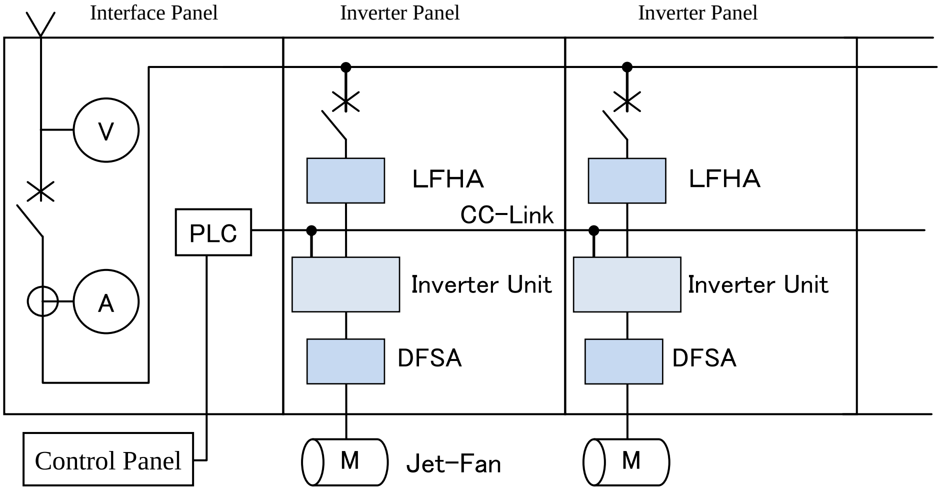

Fig. 15 Inverter Control Panel Configuration

Panel Specification

Table 4 Inverter Control Panel Specification

Item \ Series			37kW-JINV	55kW-JINV
Panel Specification	Model		Indoor Self Closed Type	
Panel Specification	Power		Main：3 Phase 3 Wire 440V 50/60Hz Control：Single Phase 100V 50/60Hz	
Panel Specification	Panel Dimension (Reference)	Incoming Panel	W700×H2350×D800mm	W700×H2350×D800mm
Panel Specification	Panel Dimension (Reference)	Inverter Panel	W700×H2350×D800mm	W800×H2350×D800mm
Inverter Specification	Inverter Capacity		37kW	55kW
Inverter Specification	Jet-fan Motor Capacity		< 33kW	< 50kW
Inverter Specification	Input Voltage		3 Phase 380～480V ±10%	
Inverter Specification	Output Voltage		3 Phase 380～480V	
Inverter Specification	Output Frequency		0～50/60Hz	
Inverter Specification	Control Method		3 Level PWM Control	
LFHA (Anti Higher Harmonics)			3 Phase Bridge with ACL+DCL Conversion Constant k=1.4	
LFHA (Anti Higher Harmonics)			12 pulse input (Smooth Condenser) with ACL+DCL Conversion Constant k =0.7(optional)	
LFHA (Anti Higher Harmonics)			Self-Excited 3 Phase Bridge (PWM Converter) Conversion Constant k=0.0(optional)	
DFSA(Anti Surge Noise)	Cable Length		< 2,000m	
DFSA(Anti Surge Noise)	Rated Current		48A	80A
JF			30～33kW×1	50～55kW×1

ATTN One JINV panel can drive two jet-fans.

INFO Sohatsu is pleased to provide consulting service for the use of JINV in any planned tunnel project.
http://www.sohatsu.com/

【Paper】 "Application of the Inverter-driven Jet-fans to the Kobe Nagata Tunnel", BHR14thISAVVT in 2011, p91-p102.
Please visit http://www.sohatsu.com/Jsite/information/i-2.htm for the abstract.


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